Agricultural Potential for Biogas Production in Croatia

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Summary

Biogas is renewable energy source with strong local character as its production depends on availability and type of feedstock at a certain location. Utilisation of slurry, manure and beddings from cattle, pig, horse, poultry and other animal breeding together with energy rich substrates such as crops and other organic materials as biogas substrates creates an interesting option both from technical and economic perspective. Other materials suitable for anaerobic digestion are comprised of various residues from agriculture (crops and vegetables), residues from food processing industry and energy crops (maize silage, grass and similar).

Primary reason for biogas production is economic gain from energy production and/or organic waste management that adds value to agriculture and food processing residues that would otherwise be treated as waste.

The purpose of the paper is to provide an overview of biogas production potential of Croatia at the level of statistical administrative units NUTS1 and NUTS2, excluding energy crops growing and agro-food imports but including the seasonality of substrate availability.

Key words

biogas, agriculture, potential assessment, Croatia

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Introduction

Biogas is renewable energy source with strong local character as its production depends on availability and type of feedstock at a certain location.

Utilisation of slurry, manure and beddings from cattle, pig, horse, poultry and other animal breeding together with energy rich substrates such as crops and other organic materials as biogas substrates creates an interesting option both from technical and economic perspective. Other materials suitable for anaerobic digestion are comprised of various residues from agriculture (crops and, vegetables), residues from food processing industry and energy crops (maize silage, grass and similar).

Biogas utilisation is perceived differently from national and individual perspective. While the government desires domestic energy sources to lessen its foreign energy dependency, the primary reason for biogas production for an individual is economic gain from energy production and/or organic waste management that adds value to agriculture and food processing residues that would otherwise be treated as waste. Assessment of renewables potential helps government to focus its policies at the renewable energy source(s) that indicate most promising results regarding potential and available technology. On the other side, theoretical potential of feedstock for biogas potential could serve as a guideline for individuals where to look for the most value added from the feedstock available.

Both scientific research (Gangl, 2004; Amon et al., 2006; Bauer et al., 2007; Kralik et al., 2008) and practice (Monnet, 2003; GERBIO, 2008) have proven that success of anaerobic digestion (AD) is closely linked with “purity” of substrate, its composition (protein/carbohydrates/fat ratio, C/N ratio, pH), digestibility and energy value. Successful biogas plants rarely rely on animal excrements only. Most often, animal excrements are considered as “a base” for AD due to their favourable characteristics (availability, low price, methanogenic bacteria, high water content, solubility etc.) but with little biogas yield. Employing concepts of co-digestions by adding other organic material with higher energy value will enhance biogas generation as well as its methane content. The material for co-digestion is regularly chosen either as locally available organic matter (i.e. potato peels, sugar beet tops and waste food) originated from food processing industry in the vicinity of biogas plant or as energy crop (i.e. maize silage) grown at fields around the plant.

The last official paper that has considered biogas potential of Croatia originated a decade ago within Development and Organisation of Croatian Energy Sector (PROHES) as National Energy Programme – BIOEN – energy from biomass and waste (Domac et al., 1998). Other research on theoretical biogas potential employs the same methodology (i.e. Navaratnasamy et al., 2007) of attributing biogas yields to all statistically recorded animals but biogas energy value attributed varies - 20 MJ/m^3 (Navaratnasamy et al., 2007), 21.6 MJ/m^3 (Batzias et al., 2005), 25 MJ/m^3 (BIOEN, 1998) – although methane content in biogas ranges from 50 to 80% (German Solar Association & Ecofys, 2005) and its lower and higher heating value amount 35.883 MJ/m^3 and 39.819 MJ/m^3, respectively.

German Bundesministerium für Verbraucherschutz, Ernärung und Landwirtschaft has published a Manual with guidelines of substrates’ characteristics (Table 1) that indicates results from German biogas practice. For the reference, Germany is the leading country in production of biogas from agricultural biomass with 41 PJ in 2006, followed by Austria (4.3 PJ) and Denmark (2.4 PJ) (EurOberv'ER, 2008).

Batzias et al. (2005) claims that for estimating biogas potential is sufficient to assume proportionality of biogas and volatile solids (organic matter) in biomass or dry matter content. Nevertheless, Batzias’ research (2005) in biogas potential employs local characteristics to the quality of animal excrements together with their spatial distribution.

Biogas plants based on AD of agricultural biomass represent mature technology of known parameters. The unknown parameter in the equation seems to be local quality of biogas substrate and the co-digestion mixture. The size of installed capacities in the EU varies from 15 kW$_{th}$ to 20 MW$_{el}$ although technology manufacturers have standardised their designs to 500 kW (two generators of 250 kW each) that could be easily extended to 1 or 1.5 MW or more (EIE BiG>East, 2007-2010).

The paper’s objective is to provide an overview of biogas production potential of Croatia at the level of statistical administrative units NUTS1 and NUTS2 with an assumption that only national agriculture resources are considered as base for biogas substrates, excluding energy crops growing but including the seasonality of substrates’ availability.

Table 1. Biogas yield and methane content according to substrate

Substrate	Total dry matter (%)		Volatile solids (% of d.m.)		Biogas yield (m^3/kg v.s.)		Methane content (%)	
	min	max	min	max	min	max	min	max
Cow slurry	8	11	75	82	0.2	0.50	60	
Cow manure	25		68	76	0.21	0.30	60	
Pig slurry	7		75	86	0.30	0.70	60	70
Pig manure	20	25	75	85	0.27	0.45	60	
Poultry manure	32		63	80	0.25	0.24	60	
Green matter	12		83	92	0.55	0.68	55	65

Source: Institut für Energie und Umwelt et al., 2006

Data sources and methodology

The analysis starts with attributing corresponding amounts of excrements (Waste Management Strategy, 2005) to the number of domestic animals by groups per NUTS1 and 2 (Agriculture Census, 2003). Goats and sheep are excluded from the biogas potential assessment due to the dominant open farming system. According to the Law on Official Statistics (OG 103/03), Croatian Bureau of Statistics has determined national classification of spatial units for statistics (NKPJS) in accordance to the EU Nomenclature of Territorial Units for Statistics (NUTS). Statistical NUTS2 territorial units for Croatia are three non-administrative units – regions: North-West or Sjeverozapadna (HR01), Panonian or Panonska (HR02) and Adriatic or Jadranska (HR03) originated by grouping of 20 counties and City of Zagreb (administrative units of lower rank corresponding to NUTS3 level) (Figure 1).

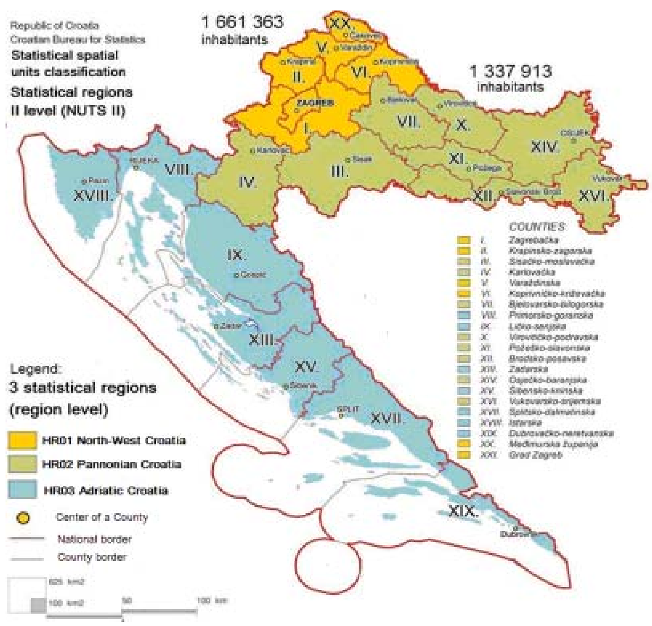

Figure 1. Map of Croatia and corresponding statistical regions (NUTS2) Source: Central Bureau of Statistics, Croatia, 2008

According to M. Maceljski, academician: "Our agricultural statistics is a mere accurate sum of inaccurate data". Consequently, data on amounts of agricultural by-products and organic waste is even less reliable as it is not based on official data but it represents estimations of different authors built upon different methodologies. The reason for choosing the use of above sources of data was the fact that they are official numbers and results so this paper could be comparable to the most research done or could be further developed if the data become more accurate.

Biogas yield and its energy value were calculated separately for each group of animals by using values from the Table 1. Research of Kralik et al. (2008) on biogas yield from pig manure and slurry fits within the values of the table. The methane lower heat value of 35.883 MJ/m^3 will be utilised for assessment of energy potential of biomass which corresponds to the assumption that biogas will be employed for electricity generation.

Given the characteristics of Croatian agriculture that are influencing biogas production from the aspect of sufficient amounts of feedstock (small farm size, different stables etc.), it has been assumed that business entities are those locations where biogas substrate exists in sufficient quantities, continuously and with constant quality in form of animal excrements. This assumption is supported by the fact that the largest categories for number of animals for family farms of Agriculture Census (2003) are 20 heads of cattle, 50 heads of pigs and more than 100 chickens while the largest categories for business entities are more than 100 head of cattle, more than 1 000 head of pigs and more than 100 000 head of poultry.

In order to override the limits of official data on numbers of animals per region, two indicators were made: feedstock density per km^2 and 3.14 km^2. If one assumes that a biogas production will occur only at locations with sufficient quantities of feedstock exists, the feedstock density indicator combines area with amount of available feedstock and indicates what the regions (here NUTS2) with considerable biogas potential are. German practice has shown that collecting manure further than 1 km from the agricultural biogas plant affects its profitability. Given the changes in transportation fuel prices, it is reasonable to assume that the radius of 1 km will expand or shrink accordingly over time if the parameters of biogas plant are to stay the same. The density of feedstock per region could indicate existence of locations with sufficient biogas potential, regardless of the organisational type of animal breeding.

Following the calculations of the base feedstock per NUTS 1 and 2 levels, the research looks for agricultural residues for AD co-substrates. To the difference of biogas substrate from animal breeding by-products that is available during the whole year, when calculating theoretical potential of agricultural biomass originating from plants (excluding energy crops) it is necessary to add additional criteria: seasonality. In that sense, the calculated theoretical potential is valid for the period of its annual availability (harvest and/or storage) only. According to the data on main crops from Statistical Yearbook (2006), Waste Management Strategy (2005) and common agricultural practice of ploughing in the green matter after harvest, the only agricultural residues to be considered are wheat and maize harvest residues. Wheat and maize straw represent a group of dry voluminous feed of low quality where utilisation of that substrate for energy purposes does not disturb the existing system. Straw could be used during the whole year with adequate storage facilities. Correspondingly, the calculated biogas potential is not adjusted with seasonal discrepancies of biogas potential.

Similar to animal excrements, energy value of plant residues vary according to species, time of harvest (percentage of dry matter), time of utilisation (seasonality and storage), preconditioning (cutting and moisturising) as well as on technology for AD itself. Despite the fact that theoretical methane yield from straw is as high as 0.503 m^3/kg of volatile solids, one should not expect degradation of straw higher than 80% in a digestor (Bauer et al., 2007). The research has shown that methane yield from wheat straw without preconditioning varies from 0.189 m^3/kg of dry matter (Gangl, 2004) to 0.267 m^3/kg of dry matter if the straw is cut to 1 mm pieces and 0.396 m^3/kg of dry matter if steam explosion is employed (Bauer et al., 2007). The same rationale could be attributed to maize straw.

Finally, it has been assumed that theoretical potential of biogas will be used to produce electricity at standard efficiency of 40% since production of electricity from renewable energy sources and cogeneration is fully described by national legislation.

The authors are fully aware of the facts that comprehensive and precise analysis on biogas potential from agricultural biomass in Croatia is not viable and that the assessment results will provide conservative guidelines instead of conclusions.

Results

Theoretical biogas potential from animal excrements per NUTS1 and 2 is shown in Table 2.

Table 2 indicates that possible theoretical contribution from animal excrements to the national energy demand in 2006 (Vuk et al., 2008) if utilised as biogas feedstock ranges from 0.78 to 2.76%. Panonian region indicated the highest potential among NUTS2 regions with 53% of biogas feedstock located in its area. The least potential for biogas production based on animal excrements was recorded in the Adriatic region (7%).

As for type of the animal, cattle breeding indicated the most of feedstock potential (55-58%), followed by pigs (27-30%) and poultry (15%) to the national biogas potential.

Including the assumption that biogas feedstock will occur in sufficient amounts at business entities only, Table 3 shows that the theoretical potential contracts for 79-81%. Corresponding contribution to the national energy demand in 2006 reduces to 0.17-0.52%.

The leading region becomes North-West region with 54% situated on its area and is followed by Slavonian region with 40% and Adriatic region (6%). Cattle is still remaining as the leading animal group (48-58%) in relation to the feedstock origin but poultry prevailed over pigs with 27-37% to 15%.

Better understanding of the biogas potential from animal excrements and its spatial distribution is provided by two additional indicators in the Tables 4 and 5 below.

Since North-West region covers the smallest area, it shows the highest density which is 51-55% more than in Pannonian region and 94% more than in Adriatic region.

Availability of other agricultural feedstock apart of animal excrements for biogas production is rather limited if energy crops are excluded. Fruit and vegetables residues are linked not with the area of harvesting but with the area of processing/consumption. Woody residues from orchards and vineyards are exempt from the biogas potential since ligneous feedstock needs different technology that is still emerging. Thus, the analysis focuses on wheat and maize harvest residues which energy value for NUTS1 and 2 levels is shown in the Table 6.

Table 2. Theoretical biogas potential from animal excrements for Croatian NUTS1 and 2 levels (TJ/year)

NUTS2	Cattle		Pigs		Poultry		Total	
	min	max	min	max	min	max	min	max
HR01	730	2 742	356	1 103	206	901	1 292	4 746
HR02	891	3 350	588	1 834	216	567	1 695	5 751
HR03	142	533	28	87	61	217	230	837
NUTS1	1 763	6 626	972	3 025	483	1 684	3 217	11 334

Table 3. Theoretical biogas potential from animal excrements at business entities for Croatian NUTS1 and 2 levels (TJ/year)

NUTS2	Cattle		Pigs		Poultry		Total	
	min	max	min	max	min	max	min	max
HR01	124	465	56	165	188	430	368	1 060
HR02	194	730	46	144	31	72	272	946
HR03	9	34	0	2	34	78	44	114
NUTS1	327	1 229	103	311	254	580	683	2 120

Table 4. Average biogas feedstock density per NUTS2 level (GJ/year per km^2)

NUTS2	Cattle		Pigs		Poultry		Total	
	min	max	min	max	min	max	min	max
HR01	84	316	41	127	24	104	149	548
HR02	39	144	25	79	9	24	73	248
HR03	6	22	1	4	2	9	9	34

Table 5. Average biogas feedstock density per NUTS2 level (GJ/year per 3.14 km^2)

NUTS2	Cattle		Pigs		Poultry		Total	
	min	max	min	max	min	max	min	max
HR01	264	993	129	400	75	326	468	1 719
HR02	121	453	79	248	29	78	229	778
HR03	18	68	4	11	8	28	29	106

Table 6. Theoretical biomass potential from wheat and maize straw by NUTS levels (TJ/year)

NUTS2	86 % d.m., without preparation			90 % d.m., with preparation		
	Family farms	Business entities	Total	Family farms	Business entities	Total
HR01	2.68	0.66	3.34	3.96	0.98	4.94
HR02	5.46	1.32	6.78	8.07	1.96	10.02
HR03	0.56	0.54	1.10	0.83	0.79	1.63
NUTS1	8.70	2.52	11.22	12.86	3.73	16.59

Table 7. Theoretical potential for biogas production from agriculture at NUTS1 and 2 levels (TJ/year)

NUTS2	Total		Business entities	
	min	max	min	max
HR01	1 295	4 751	371	1 061
HR02	1 702	5 761	277	948
HR03	231	839	44	115
NUTS1	3 229	11 351	692	2 124

Table 8. Potential for electricity generation from biogas theoretical potential (GWh/year)

NUTS2	Total		Business entities	
	min	max	min	max
HR01	144	528	41	118
HR02	189	640	31	105
HR03	26	93	5	13
NUTS1	359	1 261	77	236

Table 9. Average production of electricity according to the density of feedstock availability (MWh/year)

NUTS2	Per km2		Per 3.14 km2	
	min	max	min	max
HR01	17	61	52	191
HR02	8	28	26	87
HR03	1	4	3	12
NUTS1	6	22	20	70

If dry matter content in wheat and maize straw ranges between 86 and 90% (Mikulec, 2003) and it is attributed to the parameters given by Bauer et al. (2007), theoretical potential from agricultural plant biomass – harvest residues amounts from 11 TJ/year (without preconditioning of straw, 86% dry matter) to 17 TJ/year (cutting to 1 mm pieces, 90% of dry matter). The largest amounts of potential are located in Pannonian region (60%), followed by North-West (30%) and Adriatic (10%) region. Nevertheless, the contribution of harvest residues to total biogas potential is less than 1% and it does not change the overall biogas potentials provided for animal excrements (Table 7).

If theoretical biogas potential is to be used for electricity generation (Table 8), total theoretical potential from agricultural residues for biogas production makes 2-7% of gross electricity consumption in Croatia for 2006. If the potential is narrowed down to the business entities only, the share of corresponding biogas potential ranges from 0.43 to 1.31%. Contrasting that share with the minimum share of electricity from renewable energy sources and cogeneration of 5.8% by 2010 (Regulation on a minimum share of electricity produced from renewable energy sources and cogeneration in the electricity supply, 2007), biogas could contribute to its fulfilment according to the theoretical biogas potential assessment.

Theoretical potential via average density per square kilometre and collecting circle of 1 km radius shows how realistic generation of electricity from biogas is (Table 9).

The results indicate that theoretical biogas potential is concentrated mostly in the North-West region.

Conclusion

Theoretical biogas potential calculated at national level could provide misleading conclusions if spatial distribution of biogas feedstock is not included in the assessment. The contribution of theoretical biogas potential from agricultural residues, excluding energy crops, to the national energy demand drops by 79 to 81% if assumed that business entities are those locations where biogas feedstock will appear in sufficient amounts of homogeneous quality.

Feedstock densities indicators show that the density for North-West region and Pannonian region is 2.62 and 1.28 times larger, respectively, than the national density while Adriatic region shows feedstock density six times less than the national one.

Since biogas plants' sizes vary from 15 kW_{th} to 20_{el} MW installed capacity, none of the NUTS2 levels could be excluded from area of biogas potential sites at this stage of research.

Biogas could have contributed up to 7% (total biogas potential) or 1.31% (biogas potential at business entities) to the gross national electricity consumption in 2006.

Provided calculations and stated amounts of agricultural by-products and residues represent solely theoretical potential of biomass that should not be confused with technical or economic potential of biogas production. In further research, one should be aware of several features of the state of the art of the Croatian agriculture:

— The largest part of agricultural production occurs at family husbandries of small size and large number of parcels together with small number of heads of animals (i.e. family husbandry has, in average, seven head of cattle).
— Only part of family husbandries (so called "commercial husbandries") manages larger area and number of heads. It is difficult to identify them among aggregated data while the largest statistically observed categories start with rather small number of animals in respect of biogas production.
— Straw serves as bedding while its amount depends on variety (height) and if it is harvested low/high enough to have grain:straw ratio 1:1.
— In the case of maize harvest residues, the remaining biomass has to be left on soil (recommended ploughing in of biomass ranges from 30 to 50%) which leaves only about 30% of that biomass available for energy purposes.
— Production of manure and dry matter content depend on meal, age and level of cattle production while the amount and type of bedding depends on the farm management.

Comparing the results with the biogas potential according to the feedstock density indicators to the average electricity consumption per a household in Croatia of 3 MWh/year, one could conclude that production of electricity in agricultural AD has potential for small scale installations.

The obtained results indicate that similar differences on spatial distribution of biogas potentials could appear within the NUTS2 level, too, which calls for further research on biogas potential at smaller administrative units than NUTS1 and 2 levels. Furthermore, the research on biogas potential should extend to other potential biogas feedstock sources (i.e. food processing industry, expired foodstuff in supermarkets) in order to assess biogas potential from its residues and link them with the calculated biogas potentials at NUTS1 and 2 level, at least.

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